# Maintenance Practices — Improving Sustainability Performance of Existing Office Buildings: An Australian Case Study

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# Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Signature of Student: Production Note: Signature removed prior to publication.

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# List of Abbreviations

| | |
|---|---|
| ABARES | Australian Bureau of Agricultural and Resource Economics and Sciences |
| ACT | Australian Capital Territory |
| $A_0$ | Annual amount |
| AIQS | Australian Institute of Quantity Surveyors |
| AMCA | Air Conditioning and Mechanical Contractors Association |
| AP | Acidification potential |
| API | Australian Property Institute |
| AR4 | Fourth Assessment Report |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| AS/NZS | Australia/New Zealand Standards |
| ASTM | American Society for Testing and Materials Publications |
| Australia ICOMOS | Australia International Council of Monument and Site |
| AWC | Available Water Capacity |
| BAU | Business as Usual |
| BEEC | Building Energy Efficiency Certificate |
| BMCS | Building management and control systems |
| BMRC | Bureau of Meteorology Research Centre |
| BOMA | Building Office and Managers Association |
| BPI | Building price index |
| BWRO | Brackish water reverse osmosis |
| CAR | Cause, Action, and Result |
| CBD | Commercial Building Disclosure |
| CBDs | Central business districts, e.g. Sydney CBD |
| CEC | Commission for Environmental Cooperation |
| CEO | Chief executive officer |
| CEPA | Commonwealth Environment Protection Agency |
| CFCs | Chlorofluorocarbons |
| $CH_4$ | Methane |
| CIE | Centre for International Economics |
| CIOB | Chartered Institute of Building |
| $CO_2$ | Carbon dioxide |
| $CO_2$-e | Carbon dioxide equivalent |

| | |
|---|---|
| COAG | Council of Australian Governments |
| COP21 | 21st Conference of the Parties |
| COP | Coefficient of Performance |
| CPI | Consumer Price Index |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| EE | Energy efficiency |
| ERI | Energy Recovery Inc. |
| ESCOs | Energy service companies |
| ESD | Ecologically sustainable development |
| FMA | Facility Management Association of Australia |
| GFA | Gross floor area |
| GHG | Greenhouse gas |
| GL | Gigalitre |
| GST | Goods and services tax |
| Gt | Gigatonne |
| GWh | Gigawatt hour |
| GWP | Global warming potential |
| $H_2O$ | Water vapour |
| HCFCs | Hydrochlorofluorocarbons |
| HFCs | Hydrofluorocarbons |
| HVAC | Heating, ventilation, and air conditioning |
| IEA | International Energy Agency |
| IEC | International Electrotechnical Commission |
| IEQ | Indoor environment quality |
| IPCC | Intergovernmental Panel on Climate Change |
| IRR | Internal rate of return |
| ISO | International Organisation for Standardisation |
| kWh | Kilowatt hour |
| LCA | Life cycle assessment |
| LCC | Life cycle costing |
| LCE | Life cycle energy |
| LCI | Life cycle inventory |
| LCIA | Life cycle impact assessment |
| LE | Lighting efficiency |
| LED | Light-emitting diode |
| LPP | Litres per person |

| | |
|---|---|
| MEPS | Minimum efficiency performance standards |
| MF | Microfiltration |
| MJ | Megajoule |
| MIT | Massachusetts Institute of Technology |
| ML | Megalitre |
| MPa | Megapascal |
| MR | Materials and resources |
| NABERS | National Australian Built Environment Rating System |
| NASA | National Aeronautics and Space Administration |
| NF | Nanofiltration |
| NLWRA | National Land and Water Resources Audit |
| NP | Nutrification potential |
| NPV | Net present value |
| NS | Norway standards |
| NSW | New South Wales |
| NT | Northern Territory |
| $N_2O$ | Nitrous oxide |
| OEH | Office of Environment and Heritage (NSW) |
| OECD | Organisation for Economic Co-operation and Development |
| ODP | Ozone depletion potential |
| PCA | Property Council of Australia |
| PECC | Special Program on Climate Change |
| PFCs | Perfluorocarbons |
| PJ | Petajoule |
| PVC | Polyvinyl chloride |
| QLD | Queensland |
| RH | Relative humidity |
| RICS | Royal Institute of Chartered Surveyors |
| SA | South Australia |
| SADPTI | South Australia Department of Planning Transport and Infrastructure |
| SBS | Sick building syndrome |
| SD | Standard deviation |
| SIR | Savings to investment ratio |
| SMOB | Sustainable Maintenance of Office Buildings |
| SPSS | Statistical Package for the Social Sciences |
| SPV | Single present value |

| | |
|---|---|
| SVOCs | Semi volatile organic compounds |
| SWRO | Sea water reserve osmosis |
| T5 | Fluorescent lamps T5 |
| T8 | Fluorescent lamps T8 |
| TAS | Tasmania |
| TBL | Triple bottom line |
| UF | Ultrafiltration |
| UK | United Kingdom |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UPV | Uniform present value |
| US | United States of America |
| VAV | Variable air volume |
| VIC | Victoria |
| VCT | Vinyl composition tile |
| VOCs | Volatile organic compounds |
| VSD | Variable speed drives |
| WA | Western Australia |
| WD | Waste disposal management |
| WE | Water efficiency |
| WWR | Window to wall ratio |

# Abstract

The purpose of this thesis is to establish a method to analyse the interaction between the environment and existing buildings, to examine how the impact of existing buildings on the environment can be reduced and to suggest strategies by which any negative effects can be minimised. The investigation is focused on the development of a strategic framework to maintain and improve existing office buildings performance through sustainable maintenance strategies. It concentrates on reducing emissions generated within office buildings over their life cycle. The developed framework is a model for sustainable maintenance of office buildings entitled SMOB: an Australian case study.

Over many decades, office buildings have been recognised as a significant area contributing to the negative impacts on the environment over their life cycle, hastening climate change or global warming. In return, climate change also impacts on buildings with extreme heatwaves occurring more frequently and raising the earth's temperature. Increased temperatures make many advanced techniques as applied in buildings ineffective, which then require more energy to provide indoor comfort. The operation and maintenance phase is the longest period of operation over a building's life span. In this period, office buildings consume the highest rates of energy and water; and consequently, emit the highest rates of greenhouse gas pollution, especially $CO_2$, into the environment.

The framework of SMOB includes four indicators and 23 criteria for scheduling sustainable building maintenance through routine, ad hoc and upgrading practices which are derived from analysis of data collected through questionnaire survey, focus group discussion and a Delphi study. Case studies were used to verify the SMOB and results show that when using the model, energy and water consumption, and in particular $CO_2$ emissions in the buildings are significantly reduced, and that the buildings will satisfy environmental protection requirements. The research shows that the SMOB is well suited for assessing the costs and returned benefits against economic and environmental criteria in sustainable office building maintenance.